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High Speed Civil Transport Aerodynamic Optimization

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ANNUAL REPORT

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Introduction

This is a report of work in support of the Computational Aerosciences (CAS) element of the Federal HPCC program. Specifically, CFD and aerodynamic optimization are being performed on parallel computers. The long-range goal of this work is to facilitate teraflops-rate multidisciplinary optimization of aerospace vehicles.

This year's work is targeted for application to the High Speed Civil Transport (HSCT), one of four CAS grand challenges identified in the HPCC FY 1995 Blue Book. This vehicle is to be a passenger aircraft, with the promise of cutting overseas flight times by more than half. A successful design must far surpass the performance of the only existing comparable plane, the Concorde. Fuel economy, other operational costs, environmental impact, and range must all be improved substantially. The aircraft must be able to fly many more routes than the Concorde, and can only do so if noise production can be limited. For all of these reasons, improved design tools are required, and these tools must eventually integrate optimization, external aerodynamics, propulsion, structures, heat transfer, controls, and perhaps other disciplines. The airframe manufacturing company which succeeds in this difficult design process and successfully markets the result will gain market share and profits. The country or countries where that company operates will gain an improved balance of trade. Thus, the fundamental goal of this project is to contribute to improved design tools for US industry, and thus to the nation's economic competitiveness.

Milestones

Several milestones were identified in proposals covering the last year of research. These have been combined to form the following list, with descriptions of the work done to satisfy each:

1. Complete an Euler CFD calculation about the Boeing Ref H HSCT configuration on the Intel iPSC/860. The model will include a wing-body with engine nacelles and diverters.
2. Complete a Navier-Stokes CFD calculation about the Boeing Ref H HSCT configuration on a parallel computer. The model will include a wing-body with engine nacelles and diverters.

An Euler CFD calculation for a wing-body with nacelles has been completed, as well as a wing-nacelle-diverter case for Reference H. In the latter run, the fuselage was omitted due to operating system limitations on the number of zones. This milestone is considered complete by HPC management. The Navier-Stokes milestone is scheduled for the end of FY94. The larger memory of the Paragon or SP-2 will be needed to complete this case.

Note that Reference H is a proprietary geometry, so publication of results has been restricted. Recent rulings have partially relaxed these restrictions, but publication of quantitative results is still prohibited. The Euler calculation was presented in a restricted-attendance workshop (Reference 1).

3. Modify the combined parallel CFD code and optimizer to include a limited grid modification capability for the Haack-Adams body.
4. Validate the Haack-Adams optimization by comparing to a similar case run on a Cray computer.

These milestones have been completed, and a number of cases were run to test optimization strategies for the Haack-Adams body. Comparisons showed similar results to those obtained on Cray computers.

5. When the Intel Paragon computer at NAS is installed and available to users, begin to port the parallel code to the new machine.
6. When the Intel Paragon computer at NAS is installed and available to users, obtain and test Sisira Weeratunga's port of Parallel OVERFLOW.
7. Attempt a port of Parallel OVERFLOW to the Cray T3D when access becomes available through JNNIE.

All three of these milestones have been modified due to failures outside of this project. The Intel Paragon never attained a normal level of operational reliability. JNNIE never provided T3D accounts to any of the Ames applicants.

8. Select an optimization method and begin to parallelize it.
9. Port a parallel optimization method developed by Samson Cheung to the iPSC/860, and use it to demonstrate wing optimization which is parallel at both the solver and the optimizer levels.

The first of these milestones became redundant when Samson Cheung developed a parallel optimizer for the RFA workstation cluster. As work was

beginning on the iPSC/860 port, the acquisition of an IBM SP-2 machine was announced. At that time I changed emphasis, coupling the optimizer to the OVERFLOW flow solver on the RFA cluster, in preparation for use of the SP-2.

10. Explore the use of parallel OVERFLOW on the new parallel testbeds currently being procured.

Although the SP-2 has not been released for production, I have obtained an account and compiled OVERFLOW, along with the optimization package. Testing is beginning as this is written.

Additional Contributions

K-12 Education

One of NASA's HPC goals includes "direct involvement between NASA scientists and the K-12 community." By mentoring a high school teacher who worked at NASA Ames in 1993, I contributed to this effort. I also organized presentations for teachers from Mendocino county, directed toward finding ways for them to use CAS and HPC concepts in their classrooms.

Workgroup communication

Perceiving a need for better communication between parallel computing researchers associated with RFA, I established a series of informal technical meetings, at which progress and lessons learned could be shared. These meetings also provided the chance to establish some of the management practices planned for MCAT work under the pending contract award. These have evolved into two series: one monthly meeting has become the official RFA HPC group meeting, while another is limited to the MCAT Parallel Computing Section.

Non-milestone Research

Since some milestones were impossible or became unnecessary, some time was spent on related research. Two items are notable. First, I developed a code to produce surface and volume grids for aircraft wings. The wing shape is controlled by a wide range of design parameters. This grid generator provides a way to exercise optimization codes over a wide range of design possibilities. It has been instrumental in testing optimizers on parallel computers, where the semi-automated grid generation tools which are common on serial computers do not exist.

I also developed an optimizer based on random-direction searches in the design space. The optimizer attempts to sample the design space and move toward an optimal set of design parameters, while attempting to focus the

search on the most promising areas. This method does not rely on derivative information, which can be expensive to calculate and often misleading. While this optimizer will exhibit slower convergence than derivative-based methods on well-behaved objective functions, it provides an alternate method which may be valuable for objectives which have many local minima, discontinuities, or other difficulties.

Tools

In the process of extracting data from Boeing Reference H datasets for comparison with experiment, I found it necessary to develop a method which was not formerly available. The computational grid was not aligned with the experimental stations, so interpolation would be required. FAST (Flow Analysis Software Toolkit) provides the ability to cut through data on specified planes, but does not extract the data in a form which is useful for plotting. I developed FAST scripts to perform the data extraction to unstructured grid files, storing point locations, function values, and normal direction information. A small FORTRAN program then sorts through the unstructured data to identify vehicle surface data and organize the data into plottable form. These utilities have been requested by several researchers, and I have provided the scripts, FORTRAN source, and instruction on how to modify the tools to suit special cases.

Current Status

CFD has been parallelized within computational grids by Sisira Weeratunga, and separately by Rob van der Wijngaart. Parallelization at the grid level is provided in Weeratunga's code, and by the Medusa code of Merritt Smith. With Samson Cheung's parallel optimizer, separate CFD cases can be run concurrently. These three levels of parallelism have been tested separately, and in some cases in pairs. When all three levels are available simultaneously, the use of each level can be tailored to the problem size and to available computational resources to provide high computational rates and good parallel efficiency over a wide range of architectures.

Recent work on the RFA Cluster and the IBM SP-2 corresponds nicely to industry's expressed interest in applications based on workstation clusters. Ongoing work needs to be directed at specific areas where industry can be helped in areas they are not already addressing internally.

Future Work

The immediate future includes two types of research. First, complex single-discipline problems will be solved on parallel computers, to demonstrate improvements in the speed and capabilities of parallel CFD. Second,

optimization methods which effectively utilize parallelism on the cluster-type architectures currently favored by industry will be extended to more levels of parallelism and more practical application to complex geometries.

References

1. Philip G. Aaronson and James S. Ryan, ``OVERFLOW Code Validation Study for the Boeing Reference H," Proceedings of the First NASA/Industry High Speed Research Propulsion/Airframe Integration Workshop, Cleveland, OH, October 26-27, 1993.